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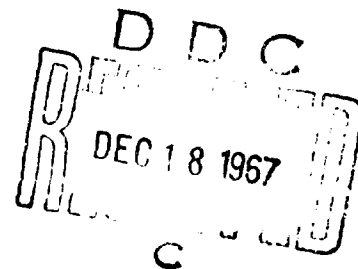
**WATER STANDARDS IN RELATION TO  
SPACECRAFT CONTAMINANTS AND  
AEROSPACE MONITORING**

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## Foreword

This study was conducted at the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio 45433, from approximately July 1963 to August 1964 under Project 7164, "Biomedical Criteria for Aerospace Flight," Task 716410, "Aerospace Sanitation and Personal Hygiene," with Dr. Arnold R. Slonim as Task Scientist. The coauthor of this report is Mr. Arthur J. Roth, Jr., Dubuque (Iowa) City Health Department Laboratory, who was available for this study via reserve duty as a Lieutenant Colonel in the Air Force Reserve and later via Contract AF 33(657)-8591 with the University of Dayton.

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This technical report has been reviewed and is approved.

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## Abstract

The types of factors in prolonged space travel (e.g., continuous exposure, reduced atmospheric pressure, gas composition, water imbalance, synergism and antagonism of constituents, etc.) that could alter the threshold limit values of contaminants are reviewed. Inhaled contaminants can add to the toxicologic problems of constituents ingested in water. Various spacecraft atmospheric contaminants especially those that are water-soluble and toxic or toxicogenic are listed. Certain constituents (e.g., benzene, toluene, and the hexanes) found to be prevalent in all closed ecological systems studied thus far may serve as general indicators of environmental contamination. For monitoring water quality, a tentative quick-test water analysis check is proposed. It is assumed that if taste, color, turbidity, pH, total dissolved solids, total nitrogen (or nitrates), and the bacteria (especially the coliforms) are all within acceptable limits, the drinking water is potable. Further studies may determine specifically which constituents should be included for rapid monitoring purposes. The feasibility of incorporating chemical and biological tests into instrumentation analysis for monitoring water quality is discussed. New chemical procedures may have to be developed for this purpose. Certain biological tests (e.g., enzymatic) are now under investigation to detect many types of microorganisms within minutes.

## SECTION I. Introduction

The first step in our goal to achieve water quality control for long-term aerospace missions was to adapt experimentally tested, advanced drinking water standards of the U.S. Public Health Service to aerospace systems (ref 1). The next exercise is to consider some of the factors inherent in long-term aerospace systems that would affect the toxicities and hence the threshold limit values of various constituents in present as well as future potable water standards. Knowledge about contaminants that have been detected in spacecraft atmospheres would provide some insight concerning the types of additional compounds that could gain access to aerospace water supplies or interact with constituents present in the water. In addition, measures must be instituted to check the water supply for its safety both routinely and in emergency, recognizing the difficulties to be encountered in monitoring water systems under aerospace conditions.

Relatively little is known to date about the various factors in aerospace systems that could alter the toxic levels of constituents in water; nevertheless, some of these factors are being considered at the present time and thus are reviewed briefly in view of their importance to establishing permanent potable water standards. A major objective of this report, however, is twofold: (1) to call attention to the types of spacecraft contaminants that are water-soluble and can be a potential hazard to water provisions, and (2) to initiate measures to develop rapid techniques for monitoring the potability of aerospace water supplies.

## SECTION II.

### Aerospace Factors

A thorough analysis of the various factors inherent in space travel that could alter the toxic levels of chemical constituents was presented at a 1963 symposium by Stokinger (ref 2). He also expressed the relationship of such factors in an equation for extrapolating threshold limit values (TLV) of constituents from industrial to spacecraft conditions. Admittedly, this mathematical expression contains many uncertainties relative to industrial limits that are based on laboratory data (e.g., ref 3), so that more information concerning long-term space missions along with toxicologic data is required to determine if an acceptable formula could be established for space applications (ref 2, 4). The variables in the Stokinger equation, nevertheless, are important factors, per se, to consider in developing threshold limit values or potable water standards for space systems.

It seems reasonable to predict that the toxicity of constituents would differ between a two-gas (e.g.,  $O_2:N_2$ ) and one-gas (e.g., 100%  $O_2$ ) system, as well as between a reduced atmosphere (e.g., 5 psi) and ambient pressure within a space capsule. Unusual temperatures and humidity would also influence toxicity. In addition, threshold limit values would be greatly altered under long, continuous exposures anticipated in space flight in contrast to intermittent industrial exposures during a 40-hour week, which is divided further into 8 hours per day (ref 2, 4). Should a one-gas ( $O_2$ ) system be used, the toxicity of certain contaminants and that of 100% oxygen may be additive.

The effects of other factors on toxicity may be somewhat less predictable and not easily amenable to quantitative measurement. For examples, the physiologic state of the individual as a result of prolonged weightlessness and restricted movement within a space capsule may have an effect on human tolerance to contaminants in general. The well-being of the space traveler would be affected also by fatigue. This has led Stokinger to consider a toxicity factor due to fatigue as well as one due to restricted movement (ref 2). Other possible factors affecting space threshold limit values of particular compounds may be those due to metabolic changes, water losses or imbalance, constant wearing of full pressure suits or ancillary equipment, time to achieve an equilibrium between intake and elimination of a contaminant, as well as rates of absorption and detoxification under long-term space conditions. In a water reclamation system, moreover, the margin of safety to incorporate in a threshold limit value may depend upon the rate of build-up or concentration of a particular contaminant.

Of importance to the problem of establishing toxic limits of compounds in space systems is the nature of the interaction of some of these factors, such as by synergism, summation, or antagonism. It is not only difficult but premature to predict in the absence of experimentation how some of these factors would interact over a given period. As indicated above, those for environmental conditions (pressure, temperature, etc.) may be relatively fixed, whereas others may be undeterminate and depend on the toxic nature of the constituent itself. This is exemplified by Stokinger who states that in a reduced atmosphere, pulmonary absorption may be proportionally reduced, e.g., one-third at 5 psi, and that toxic levels of some constituents may double per 10-18F rise of temperature increment; on the other hand, 100% oxygen can potentiate the toxicity of a chemical but antagonize the effects due to fatigue (ref 2). Thus, the direction (increase or decrease) and degree of change of threshold limit values of some contaminants can not be generalized, but would depend partly on the nature of the contaminant itself and partly on the predominant interaction (synergism or antagonism) that would occur under conditions of long-term space flight.

Although the toxicity in an ambient environment is known concerning various spacecraft contaminants, some of which will be identified below, relatively little work has been done on exposure of animals to contaminants in any of numerous spacecraft conditions (5 psi, 100% O<sub>2</sub>, immobility, etc.). Experimentation to determine toxic levels of compounds under individual space-type conditions followed by exposure to an integrated space environment must be undertaken to establish more realistic threshold limit values or potable water standards for space systems.



### SECTION III.

## Spacecraft Contaminants

Unless capsule atmospheric contaminants are prevented either from gaining access to the water recycling system and hence ingested or, by virtue of their inhalation, from potentiating the toxic effects of constituents absorbed through other routes in the body, they could add appreciably to the toxicologic problems of long-term aerospace systems. Even with good atmosphere control, a temporary breakdown in any part of the air purification facilities could bring about the same results. Thus, it is important to recognize these spacecraft contaminants so as to be prepared to monitor as well as correct for their presence particularly in water, which is the main concern of this report.

Up to 60 contaminants in the atmospheres of the various Project Mercury spacecraft have been identified by Saunders (ref 5-9). Twenty water-soluble organic compounds (or their reaction products) have been extracted from a compilation of most of these spacecraft contaminants (ref 7) and are tabulated with relevant water quality data (ref 10, 11) in table I.

Some of the contaminants detected by Saunders are not limited to spacecraft, but have been reported also aboard a nuclear submarine (ref 12). Although the equipment aboard spacecraft and nuclear submarines are different, apparently some chemicals are common to most closed, manned and instrumented chambers, such as toluene, benzene xylene, hexane and the chlorohexanes (ref 8, 12). Moreover, a similarity to spacecraft contaminants was noted by Saunders (ref 13) for over half of the 29 constituents detected in the Aerospace Medical Research Laboratories Environmental Test Chamber, which was used in conducting a 3-man, 30-day simulated aerospace flight. In the atmospheres of all three types of enclosed chambers, carbon dioxide, toluene, and benzene were the most common compounds. Generally, however, all sealed atmospheric contaminants represent almost all classes of organic compounds (ref 7); many have been classified toxicologically (ref 14) or have known threshold limit values (ref 3). However, because they are present in such great numbers, it appears virtually impossible to monitor all or even a sizeable fraction of them. For this reason, every effort should be made to eliminate or reduce as much as possible all contaminants from contacting any part of the aerospace water recycling system. At the same time, however, consideration should be given to determining which of the contaminants that are prevalent and relatively toxic or toxicogenic might serve as "indicators" of atmosphere control breakdown. These indicator constituents should be considered for future potable water standards either individually or perhaps as part of the organic carbon fraction or chemical oxygen demand (COD). Moreover, if the organic contaminants under laboratory testing are shown to increase the organic level in water, then this fraction should be incorporated in any quick-test monitoring technique.

For additional information on the nature of contaminants detected in closed systems of manned chambers, submarines and spacecraft, the reader is referred to several other papers presented at a 1963 symposium (e.g., ref 2, 4, 9) on toxicity in the closed ecological system (ref 15). These include papers on closed system contaminants in general by Wessel (p 77) and Honma and Rinehart (p 155), on aerosols, ions, etc., by Kinsey (p 1) and Punte (p 305), on microbial contaminants by Irvine (p 55), on nuclear submarine contaminants by Carhart (p 171) and Johnson (p 223), and on space vehicular contaminants by Donner and Weber (p 181), Weber (p 233), and Quattrone (p 269).

TABLE I  
SOME POTENTIAL WATER SOLUBLE CONTAMINANTS (OR SOURCES)  
FOUND IN THE ATMOSPHERES OF MERCURY SPACECRAFT\*

| Contaminant         | Formula  | Concentration<br>in Atmosphere<br>(ppm) <sup>†</sup> | General Remarks (solubility g/100g<br>water; oral LD <sub>50</sub> in mg/kg of rats;<br>and/or taste levels) |
|---------------------|--|--|--|
| Freon-114           | CF <sub>2</sub> Cl-CF <sub>2</sub> Cl            | 60-6000  | Insoluble, but source of soluble gases at<br>high temperature (Cl <sub>2</sub> , HCl, HF, etc.)              |
| Ethylene Dichloride | CH <sub>2</sub> Cl-CH <sub>2</sub> Cl            | 0-40   | 0.869 @ 20C; 770 mg/kg   |
| Toluene             | C <sub>6</sub> H <sub>5</sub> CH <sub>3</sub>    | 3-20   | 0.047 @ 16C; 7 g/kg  |
| n-Butyl Alcohol     | C <sub>4</sub> H <sub>9</sub> OH                 | 0-4  | 7.9 @ 20C; 2.75, 4.36 mg/kg†   |
| Ethyl Alcohol       | C <sub>2</sub> H <sub>5</sub> OH                 | 0-3  | Very soluble; acute toxicity—7.4 mg/kg   |
| Vinyl Chloride      | CH <sub>2</sub> =CHCl                            | 0-3  | Slightly soluble   |
| Freon-11            | CFCl <sub>3</sub>                                | 0-3  | Similar to Freon-114 above   |
| Methylene Chloride  | CH <sub>2</sub> Cl <sub>2</sub>                  | 0-2  | 2.0 @ 20C  |
| Acetone             | CH <sub>3</sub> COCH <sub>3</sub>                | 0-1  | Very soluble; 9.75 g/kg  |
| Methyl Ethyl Ketone | CH <sub>3</sub> COC <sub>2</sub> H <sub>5</sub>  | 0-1  | Very soluble; 3.98 g/kg  |
| n-Propyl Alcohol    | C <sub>3</sub> H <sub>7</sub> OH                 | 0-1  | Very soluble; 1.87, 3.3 g/kg†  |
| Acetaldehyde        | CH <sub>3</sub> CHO                              | 0-1  | Very soluble; 1.93 g/kg  |
| Ethyl Acetate       | CH <sub>3</sub> COOC <sub>2</sub> H <sub>5</sub> | 0-1  | 8.6 @ 20C; 5.62 g/kg   |
| Methyl Alcohol      | CH <sub>3</sub> OH                               | 0-1  | Very soluble; 10cc fatal to man  |
| 1,4-Dioxane         | (CH <sub>2</sub> ) <sub>4</sub> O <sub>2</sub>   | 0-1  | Very soluble   |
| Ethylene            | CH <sub>2</sub> =CH <sub>2</sub>                 | 0-1  | Very soluble   |
| Benzene             | C <sub>6</sub> H <sub>6</sub>                    | 0-1  | 0.082 @ 22C; 5.6, 5.7 g/kg†;<br>tasteful 0.5 — 4.5 mg/liter  |
| Trichloroethylene   | CHCl=CCl <sub>2</sub>                            | 0-1  | 0.10 @ 20C; 5.86 g/kg (dogs)   |
| 3-Methyl-2-Butanone | CH <sub>3</sub> COC <sub>3</sub> H <sub>7</sub>  | 0-1  | Very slightly soluble  |
| Freon-114 unsymm.   | CFCl <sub>2</sub> CF <sub>3</sub>                | 0-1  | Similar to Freon-114 above   |

\*Extracted from data of R. A. Saunders, U. S. Naval Research Laboratory (ref 7); toxicity data (ref 10) provided  
by G. W. Burke, Jr., USPHS, Washington, D. C.

†Values are amounts of contaminants desorbed from carbon thus represent minimal concentrations.

‡Oral LD<sub>50</sub> by different investigators.

## SECTION IV.

### Aerospace Monitoring

The difficult task of monitoring the quality and safety of potable water during space travel must be considered at the present time. At this stage of development, analysis of nearly all of the constituents in potable water, such as those listed in the aerospace standards of a previous report (ref 1), involves laborious and intricate procedures and, frequently, special instrumentation, with none of the chemical tests, for example, adapted to measurement under conditions of weightlessness. To develop a space kit to monitor almost all potable water constituents, including some as yet unidentified, appears to be an almost insurmountable task. More attainable within present time limitations would be the effort of determining which constituents could be selected to reflect the quality of potable water rather than of attempting to adapt a whole battery of tests to aerospace conditions. Thus, the major problems in this area deserving immediate attention would be reduced to: What tests can serve as "indicators" of water quality and safety? How can they be modified for measurement under weightlessness and other restrictive conditions of space travel?

On this premise, starting with the first question, it appears practical to recommend as a basis for further research and development a tentative quick-test water analysis that would indicate with a high probability that the water is safe if all the parts of the test checked out satisfactorily. In this section an attempt will be made to select certain constituents from the aerospace potable water standards for developing rapid methods to check the water routinely and during temporary breakdown of the reclamation system. No test will be excluded at this time solely on the basis of capability of analysis under aerospace conditions. In certain cases, however, some development work has already been initiated and will be discussed below. The constituents that are considered here with their characteristic acceptability limits as well as emergency levels in certain cases are presented in table II.

TABLE II  
QUICK-TEST WATER ANALYSIS CHECK (TENTATIVE)

| <i>Type of Test</i>  | <i>Limit of Acceptability</i>   |
|--|---|
| Taste  | Subjective acceptance to all modalities   |
| Color  | Subjective visual acceptance  |
| Turbidity  | Moderately cloudy (ca 25 Jackson units; in emergency: 50 units)   |
| pH   | 5.0-9.5   |
| Total Dissolved Solids*  | 1000 mg/l (In emergency: 2000 mg/l)   |
| Total Nitrogen<br>(NO <sub>3</sub> , NO <sub>2</sub> , NH <sub>3</sub> ) | 100 mg/l as NO <sub>3</sub> /NO <sub>2</sub> or 23 mg/l as N (In emergency: 200 mg/l as NO <sub>3</sub> /NO <sub>2</sub> or 45 mg/l as N) |
| Bacteriological Test†  | No detectable coliform cells/100 ml/6 hr incubation (In emergency: no detectable coliforms/100 ml/4 hr incubation)                        |

\*See text for equivalent tests such as specific conductance.

†Acceptability limits refer to the Radioisotope (C<sup>14</sup>) Coliform Test of G. V. Levin. Note in text more recent technique by Levin that detects smaller numbers of microorganisms within minutes.

The recommendation proposed at this time is that if taste, color, turbidity, pH, total dissolved solids (or equivalent specific conductance), nitrogen (or nitrate), and the bacteria (especially the coliforms) are all within acceptable limits, then the water is safe to drink. Additional comments regarding each part are presented below.

### **TASTE**

Of all potable water tests aboard a spacecraft, those of taste and odor would be the poorest and least quantitative.\* Odor of water would be difficult to manage in space because the odor-carrying air from the water and the water, itself, would be inseparable. The factor of gradual adaptation to buildup of metals in water renders the taste test relatively qualitative in nature. However, for detecting any abrupt change in water quality, it should not be overlooked and may be the most sensitive and rapid indicator of water quality.\*

### **COLOR**

The color of water in most instances is a good and quick index of quality. Moreover, a quantitative measure of color would be possible in aerospace monitoring, because serialized standards (ref 16), are available and could be miniaturized into a small pack of sealed vials, representing different levels of chloroplatinate ions or color units. If this test were to become part of an automated battery of procedures, the color could be determined photometrically.

### **TURBIDITY**

Not all contaminants impart color nor do all add to the suspended matter in water. However, turbidity, which depends upon the size, shape, and refractive index of matter, can thereby be influenced by many colorless, organic and inorganic particles (ref 16). For this reason, consideration of both color and turbidity would be more valuable than either physical property alone. Although commercial instruments are available that are calibrated against the Jackson candle turbidimeter, more development work is required to adapt turbidity measurement to aerospace applications.

### **pH**

The hydrogen ion concentration is indicative not only of the stability of the water, but along with measurement of alkalinity as  $\text{CaCO}_3$  reflects the efficacy of any water-treatment process, such as chlorination and coagulation (ref 16). Concerning water stability, a pH of water outside the range 5.0-9.5 should be evaluated to determine what is contributing to the acidic or basic condition of the water. In regard to treatment processes, any abnormally large change in pH would indicate an alteration or malfunction in water treatment. If chemical treatment of water becomes necessary in aerospace, alkalinity measurements may have to be included. Normal alkalinity is a function of pH and total alkalinity (ref 16). To keep normal alkalinity (as  $\text{CaCO}_3$ ) below threshold limits, i.e., 120 mg/l (ref 17), total alkalinity must be reduced with increasing pH (ref 17). Various indices (e.g., stability index) have been employed to indicate  $\text{CaCO}_3$  scale-forming tendencies and corrosive properties of water. In addition, many nomographs are available to estimate the hydroxyl ion concentration in terms of  $\text{CaCO}_3$  based on knowledge of pH, temperature, and total dissolved solids; if total alkalinity is known in addition to the three variables cited, any of the three forms of alkalinity and free  $\text{CO}_2$  in water could be determined nomographically (ref 16). Modification of present pH electrometric procedures, which are subject to less

\*G. W. Burke, Jr. (USPHS, Washington, D. C.): Personal communication (September 1963).

restrictions (e.g., interference) than colorimetric methods (ref 16), appears feasible for aerospace monitoring.

### **TOTAL DISSOLVED SOLIDS**

This complex includes all of the dissolved constituents in water. A level beyond 1000 mg/l TDS (with low sulfates) is not serious and up to 2000 mg/l is acceptable in emergency (ref 1). However, if this higher level is reached abruptly rather than through gradual buildup, serious gastrointestinal discomfort (diarrhea, etc.) would result in the unaccustomed individual. Normally, TDS is measured as the total residue after ignition of water at a high temperature. A total residue analysis by this procedure appears at present impractical for monitoring purposes aboard a spacecraft. However, since specific conductance measurements are roughly proportional to the filtrable residue, they may serve as useful indicators even though conductivity and residue analyses are not always closely correlated (ref 16). Essentially, specific conductance reflects the amount of ionized substances in water that are capable of carrying a current; thus, it is affected by the types of ions, their actual and related concentrations and ionic strength, and temperature (ref 16). The procedure requires an A-C source, wheatstone bridge, specific conductance cell and constant temperature bath. Any means of maintaining the water temperature between 20 and 30C would satisfy the temperature requirement of this test, in which conductance varies directly with the conductance cell constant and indirectly with the sample resistance. A specific conductance threshold could be established for a particular potable water supply if repeated laboratory water analyses were to show a relatively constant level of TDS with about the same proportion of ions.\* Moreover, the "amount of dissolved matter in a sample may often be estimated by multiplying the specific conductance by an empirical factor" that may vary from 0.55 to 0.9, depending on the dissolved substances and temperature of measurement; high factors are required for saline waters and lower factors for water containing considerable hydroxide or free acid (ref 16). Conversely, this empirical factor could be determined first in the laboratory by dividing the dissolved residue by the specific conductance of the particular potable water supply in question. In addition to specific conductance for checking fixed filtrable residue, ion-exchange procedures have been employed (ref 16) and may be useful for monitoring purposes. On the other hand, the organic content of the water may be appreciable and thus need to be monitored as well.

### **TOTAL NITROGEN**

The nitrogen content of the water could be a serious problem in potability because of its association with microbial pollution and, if in the oxidized state (nitrate and nitrite), its toxicity to man. A nitrogen test would, therefore, provide an additional measure for assessing the presence or absence of microbial pollution. Several forms of nitrogen are possible in spacecraft waters; these include albuminoids, ammonia, nitrates and nitrites. The albuminoids reflect the proteinaceous compounds (amino acids, peptides, etc.) that result from animal and plant organisms in water supplies and thus indicate organic pollution. Ammonia is excreted by man as well as produced as a major end-product of microbial metabolism. There is no USPHS water standard for ammonia, per se, although the threshold limit of ammonia in air was reduced one-half in 1963 to 50 ppm from 100 ppm of the previous year (ref 3). The nitrates and nitrites are excreted by man, but also represent terminal oxidation of biological activity. The presence of nitrate-nitrite in water at high levels (100 mg/l or up to 200 in emergencies) is not as toxic as some of the other constituents near their threshold limits (ref 1, e.g., CN, Cr<sup>6+</sup> and Pb), nor are the taste and laxative effects as objectionable as those of the various sulfates, phosphates and certain metals. However, the nitrates as well as the ammoniacals provide a rich medium for the growth of microorganisms, in which growth rate

\*G. W. Burke, Jr. (USPHS): Personal communication (September 1963).

is proportional to nitrogen content up to a point. If the interior of the spacecraft is sterilized or means are provided for keeping the total count of organisms in all areas to a minimum, other specific chemical tests might be more important to monitor than the nitrogens. Thus, the problem regarding the chemical quality of water remains: Which constituents should be selected for monitoring the quality of potable water? Much exploratory research (including space flight data) is needed to answer this question.

#### TEST FOR COLIFORM AND OTHER ORGANISMS

The coliform group of microorganisms has been used by the U.S. Public Health Service as an index of enteric microbial contamination of water. The standard procedures used for analyzing the bacterial content of water are not suitable at the present time for aerospace applications because of too many types of equipment needs and long periods of time for analysis (e.g., at least 24 hours are required for all standard coliform tests, ref 18). Some methods are being developed that have shortened the assay time (e.g., ref 18, 19). One technique that has gained wide attention lately because of its applicability to aerospace systems is the rapid radioisotope ( $C^{14}$ ) method of Levin (refs 19-21), which has been miniaturized for the NASA-sponsored *Culliver* program for Mars exploration (ref 22). Essentially, the Levin technique is applicable to all organisms producing  $CO_2$ . However, the coliforms are differentiated from other organisms by incubation at a  $44^\circ C$  temperature on MacConkey's Medium containing less than 10 microcuries of  $C^{14}$  formate in a 1-inch diameter planchet; absorption of the gas occurs on a  $Ba(OH)_2$ -saturated pad under the planchet cover, and the beta particles are then counted in a routine manner. The procedure has been completed in 4 hours and checked satisfactorily against standard methods. Although 6 hours would give adequate time to detect coliform cells by this method, the appearance of no cells in 4 hours would be acceptable in cases of emergency.\*

A different technique that has been developed recently by Levin, under Navy sponsorship, appears to be superior and have greater potential than other procedures for space applications. It is a rapid enzymatic test requiring less than a few minutes, including enzyme-substrate reaction, to detect the presence of microorganisms. At the present time, it appears to be very sensitive, non-specific, and capable of detecting both small animal and plant organisms (e.g., protozoa and algae)\* This novel technique, upon further refinement, will probably be one of the methods of choice for monitoring the presence of organisms in both the atmosphere and water of spacecraft.

#### GENERAL CONSIDERATIONS

Chemical and biological tests, such as those just described, will have to be modified or new procedures discovered towards developing instrumentation for rapid monitoring of water quality aboard a spacecraft. Instrumentation analysis has in recent years been under development for various types of closed systems. The various methods, problem areas, and suggestions for improving monitoring technology have been reviewed at a closed ecological system toxicity symposium (e.g., refs 23-26). The same methods and problems involved in monitoring atmospheric contaminants are applicable to instrument monitoring of spacecraft water supplies. For precise information on the subject, the reader is referred again to the published proceedings of this symposium (ref 15), which include papers evaluating the use of gas chromatography, mass and infrared spectrometry by Honma and Rinehart (p 155) and Weber (p 233), gas chromatography by Donner and Weber (p 181), spectrophotometry by Watson (p 201), carbon sampling and instrumentation for organic contaminants by Johnson (p 223), and detection and alarm systems for warning of dangerous concentration levels of contaminants by Strange (p 257). These papers provide information on the present state of knowledge of monitoring capabilities.

\*Dr. G. V. Levin (Hazelton Labs, Inc., Washington, D. C.): Personal communication (November 1963).

## SECTION V.

### General Discussion

Some of the problems facing aerospace toxicologists and physiologists would become less burdensome and complicated as the effects of space travel become known on nutrition, absorption, metabolism, detoxification, excretion, and muscular as well as cellular activity. Limited evidence exists to show that certain physiological processes are unaltered by weightlessness; e.g., in Project Mercury, especially the longest orbital flight, the postflight urine properties were not significantly different from those of preflight. Most of the other functional activities examined were unchanged or within normal variation, except for a few alterations, such as reversal of the neutrophil/lymphocyte ratio, blood pressure (hypotension) and dehydration, all of which returned to normal after termination of the flight (ref 27). On the other hand, relative immobility for long periods resulted in a gradual depletion of certain ions such as calcium and to a less extent phosphorus, as well as a lowered physical work capacity (ref 28). From these sources of information, it is evident that more study is needed to assess fully the effects of weightlessness; one condition, however, that of restricted movement is contraindicated for long-term missions.

The types of factors in prolonged space travel that could alter the threshold limit values of constituents were briefly reviewed. These included continuous exposure, reduced atmospheric pressure, gas composition, fatigue, metabolic changes, water losses, synergistic and antagonistic effects of constituents, etc. Although the effects of some factors such as those for environmental conditions (e.g., pressure and temperature) are somewhat predictable, the majority is not easily amenable to quantitative measurement. Only further research can determine the effects of aerospace conditions and more realistically express toxicity, thereby providing a better margin of safety in establishing water standards.

Spacecraft contaminants would become a problem to personnel in the event of a breakdown of the atmosphere purification system or water recycling and storage units. Even were the contaminants not to come in direct contact with the water, their inhalation might potentiate toxic reactions with ingested constituents. A large number of compounds have been found in the atmospheres of Mercury spacecraft; some are water-soluble and very toxic. In view of the large number representing all classes of organic compounds, it may be more practical to establish monitoring procedures for the most prevalent constituents, such as benzene, toluene, and the hexanes, which have been identified also in other enclosed, manned and instrumented chambers. Possibly, an organic carbon analysis may contain the major portion of these constituents in water, and consideration should be given to evaluating this or an equivalent method for rapid monitoring purposes.

Since hundreds of chemical constituents as well as microbiological species may be present in potable water, it would be advantageous to select certain prevalent, potentially dangerous, or toxicogenic constituents to reflect abnormal changes in the water or indirectly in environmental conditions. The major problems would then be reduced to selection of *indicator* tests and modification of procedures for aerospace analysis. As a basis for further exploration, seven physical, chemical and bacteriological tests (as a minimum) for monitoring potable water have been proposed at this time. If, in a quick-test analysis, the taste, color, turbidity, pH, total dissolved solids (or equivalent specific conductance), nitrogen (or nitrate), and the bacteria (especially the coliforms) all were within acceptable limits, then the space water supply would be safe to drink. Certain of these tests although subjective, e.g., taste and color, are good indices of water quality. Color and turbidity together provide a better evaluation than either one alone, since all contaminants do not impart color or add to the suspended matter in water.

The pH is one of the most useful variables for monitoring water; it is generally indicative not only of water stability, but the efficacy of any treatment process (e.g., chlorination). Electro-metric is preferred to colorimetric pH analysis for aerospace monitoring. By nomographic analyses, pH (along with temperature, total dissolved solids, and alkalinity) enters into the calculation of hydroxyl ion concentration in terms of  $\text{CaCO}_3$ , various alkalinities, and the free  $\text{CO}_2$  content in water.

One of the most important fractions in potable water is the total dissolved matter of which the ionic components, usually the major portion, can be measured by specific conductance. A specific conductance threshold value could be determined in the laboratory for water from a particular reclamation unit and used to reflect an equivalent concentration of total dissolved solids. Conversely, the TDS level can be estimated by multiplying the specific conductance by an empirical factor, which also can be determined in the laboratory for a particular water supply (ref 16). This factor, ranging from 0.55 to 0.9, covers water having either much hydroxide or free acid to high salt concentrations, respectively. In addition, ion-exchange methods have been proposed for checking the filtrable residue of water. On the other hand, the organic content of the water may have to be monitored if the data so indicate.

Nitrogenous substances are included for rapid monitoring because of their importance in supporting the growth of microorganisms and their high concentration in the liquid wastes to be used in water reclamation. If adequate means exist to maintain water free of microorganisms, tests for nitrates and ammonia may be replaced by others that might be more important for monitoring water quality, such as organic carbon and chemical oxygen demand. The latter group may be added as a separate monitoring constituent.

In regard to detection of microorganisms in water, a reliable 4-6 hour procedure has been used to measure bacteria, particularly coliform organisms, and has been instrumented and miniaturized for space exploration of Mars (ref 22). However, enzymatic tests are being developed that have the potential to detect the presence of all organisms within minutes and, thus, would be valuable for aerospace applications.

To what degree any of the chemical and biological tests can be incorporated into rapid instrumentation analysis of spacecraft water remains to be seen. Various complex instrumentation techniques are available for monitoring spacecraft atmospheric contaminants that may be of value to monitoring water quality. The effects of space conditions on the choice of analytical techniques and suggestions for improving the monitoring technology were presented recently by Honma and Rinehart (ref 23). The recommendations of these workers were threefold: "(1) miniaturization of analytical instruments that are faster, more sensitive, more versatile and more durable than existing ones; (2) exploitation of chemical and physical phenomena not presently used as a basis for analytical tools; and (3) continued advancement in automated analysis and data-handling methods."



## References

1. Slonim, A. R., and A. J. Roth, Jr.: *Provisional Aerospace Water Standards - 1964*, AMRL-TR-66-252, Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio, Dec. 1966.
2. Stokinger, H. E.: "Validity and Hazards of Extrapolating Threshold Limit Values to Continuous Exposures," In: *A Symposium on Toxicity in the Closed Ecological System*, Palo Alto, Calif., 29-31 July 1963, pp 103-123 (see ref 15).
3. *Threshold Limit Values for 1963*: Adopted at the 25th Annual Meeting of the Amer. Confer. of Governmental Hygienists, Cincinnati, Ohio, May 1963. (Reprints available from A.C.G.H., 1014 Broadway, Cincinnati, Ohio.)
4. Thomas, A. A., and K. C. Back: "The Environmental Toxicity of Space Cabin Atmospheres," In: *A Symposium on Toxicity in the Closed Ecological System*, 29-31 July 1963, pp 135-142 (see ref 15).
5. Saunders, R. A.: *Analysis of the Spacecraft Atmosphere*, NRL Report 5816, Naval Research Laboratory, Washington, D. C., Oct. 1962.
6. Saunders, R. A.: *Analysis of Atmospheric Contaminants from Sigma VII*, NRL Letter Report 6110-163A, 28 May 1963.
7. Saunders, R. A.: "Contamination Pattern in the Enclosed Atmospheres of Mercury Spacecraft," In: *Proceedings of the First Space Vehicle Thermal and Atmospheric Control Symposium*, Dayton, Ohio, 12-13 February 1963, ASD-TDR-63-260, Wright-Patterson AFB, Ohio, April 1963.
8. Saunders, R. A.: *Preliminary Results of Analysis of Atmospheric Contaminants Recovered from MA-9 (Faith VII)*, NRL Letter Report 6110-298A, 22 Oct. 1963.
9. Anderson, W. L., and R. A. Saunders: "Evolution of Materials in the Closed System," In: *A Symposium on Toxicity in the Closed Ecological System*, 29-31 July 1963, pp 9-18 (see ref 15).
10. McKee, J. E., and H. W. Wolf: *Water Quality Criteria*, 2nd Ed., State of California Water Quality Control Board, Sacramento, Publication No. 3-A, 1963.
11. *Handbook of Chemistry and Physics*, 42nd Ed., The Chemical Rubber Publishing Company, Cleveland, 1960-1961.
12. Unstead, M. E., J. G. Christian, and J. E. Johnson: *A Study of the Organic Vapors in the Atmosphere of the USS Skate*, NRL Memorandum Report 1057, June 1960.
13. Saunders, R. A.: *Atmospheric Contamination in the AMRL Environmental Test Chamber*, NRL Letter Report 6110-224A, 17 July 1963.
14. Stokinger, H. E., and R. L. Woodward: "Toxicologic Methods for Establishing Drinking Water Standards," *J. Am. Water Works Assn.*, 50, 515, 1958.
15. *A Symposium on Toxicity in the Closed Ecological System* (Honma, M., and H. J. Crosby, Eds.), Palo Alto, California, 29-31 July 1963 (AD No. 440942).
16. *Standard Methods for the Examination of Water and Wastewater*, 11th Ed., Am. Public Health Assn., Inc., New York, 1960.

17. USPHS: "Public Health Service Drinking Water Standards 1946," *Public Health Reports*, 61, 671, 1946 (Reprint No. 2697).
18. Hiser, L. L., and A. W. Busch: An 8 Hour Biological Oxygen Demand Test Using Mass Culture Aeration and COD." Presented at the Annual Meeting of the Water Pollution Control Federation, Seattle, Wash., October 1963.
19. Levin, G. V., V. R. Harrison, W. C. Hess, A. H. Heim, and V. L. Stauss: "Rapid, Radioactive Test for Coliform Organisms," *J. Am. Water Works Assn.*, 51, 101, 1959.
20. Levin, G. V., V. L. Stauss, and W. C. Hess: "Rapid Coliform Organism Determination with  $C^{14}$ ," *J. Water Pollution Control Federation*, 33, 1021, 1961.
21. Levin, G. V.: "Rapid Microbiological Determinations with Radioisotopes," *Adv. in Applied Microbiol.*, 5, 95, 1963.
22. Levin, G. V., A. H. Heim, J. R. Clendenning, and M. F. Thompson: "Gulliver - A Quest for Life on Mars," *Science*, 138, 114, 1962.
23. Honma, M., and R. W. Reinhart: "Methods of Detection and Quantification," In: *A Symposium on Toxicity in the Closed Ecological System*, 29-31 July 1963, pp 155-169 (see ref 15).
24. Donner, W., and T. B. Weber: "Present and Potential Instrumental Methods for Manned Spacecraft," In: *A Symposium on Toxicity in the Closed Ecological System*, pp 181-199 (see ref 15).
25. Johnson, E.: "Atmosphere Monitoring in the Nuclear Submarine," In: *A Symposium on Toxicity in the Closed Ecological System*, pp 223-232 (see ref 15).
26. Weber, T. B.: "Atmosphere Monitoring in the Space Cabin Simulator," In: *A Symposium on Toxicity in the Closed Ecological System*, pp 233-255 (see ref 15).
27. NASA: *Mercury Project Summary Including Results of the Fourth Manned Orbital Flight*, NASA SP-45, Houston, Texas, May 1963.
28. Birkhead, N. C., J. J. Blizzard, J. W. Daly, G. J. Haupt, B. Izzekutz, Jr., R. N. Myers, and K. Rodahl: *Cardiodynamic and Metabolic Effects of Prolonged Bed Rest*, AMRL-TDR-63-37, Aerospace Medical Res. Labs., WPAFB, Ohio, May 1963.

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| <p>The types of factors in prolonged space travel (e.g., continuous exposure, reduced atmospheric pressure, gas composition, water imbalance, synergism and antagonism of constituents, etc.) that could alter the threshold limit values of contaminants are reviewed. Inhaled contaminants can add to the toxicology problems of constituents ingested in water. Various spacecraft atmospheric contaminants especially those that are water-soluble and toxic or toxicogenic are listed. Certain constituents (e.g., benzene, toluene, and the hexanes) found to be prevalent in all closed ecological systems studies thus far may serve as general indicators of environmental contamination. For monitoring water quality, a tentative quick-test water analysis check is proposed. It is assumed that if taste, color, turbidity, pH, total dissolved solids, total nitrogen (or nitrates), and the bacteria (especially the coliforms) are all within acceptable limits, the drinking water is potable. Further studies may determine specifically which constituents should be included for rapid monitoring purposes. The feasibility of incorporating chemical and biological tests into instrumentation analysis for monitoring water quality is discussed. New chemical procedures may have to be developed for this purpose. Certain biological tests (e.g., enzymatic) are now under investigation to detect many types of microorganisms within minutes.</p> |  |                                    |

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